

CP violation in charm decays at Belle

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We have searched for CP violation of charmed mesons in the decays $D \rightarrow K_S^0 P$, where D denotes D^0 and $D_{(s)}^+$, and P denotes the pseudo-scalar mesons π^+ , K^+ , π^0 , η , and η' . No evidence of CP violation in these decays is observed. We also have measured the CP asymmetry difference between the Cabibbo suppressed decay $D^+ \rightarrow \phi \pi^+$ and the Cabibbo favored $D_s^+ \rightarrow \phi \pi^+$ decays in the region of $|M(K^+ K^-) - M_{PDG}^\phi| < 16 \text{ MeV}/c^2$. The measured asymmetry is corrected for the residual asymmetry due to detector effects, and the contributions of both CP and forward-backward asymmetries are determined. These results are obtained on a large data sample collected at and near the $\Upsilon(4S)$ resonance with the Belle detector operating at the KEKB asymmetric-energy e^+e^- collider.

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Violation of the combined Charge-conjugation and Parity symmetries (CP) in the standard model (SM) is produced by a non-vanishing phase in the Cabibbo-Kobayashi-Maskawa flavor-mixing matrix [1], where the violation may be observed as a non-zero CP asymmetry defined as

$$A_{CP}^{D \rightarrow f} = \frac{\Gamma(D \rightarrow f) - \Gamma(\bar{D} \rightarrow \bar{f})}{\Gamma(D \rightarrow f) + \Gamma(\bar{D} \rightarrow \bar{f})} \quad (1)$$

where Γ is the partial decay width, D denotes a charmed meson, and f is a final state.

In the SM, the charged charmed meson decays for which a significant non-vanishing CP violation ($\mathcal{O}(0.1)\%$ or lower [2]) is expected are singly Cabibbo-suppressed (SCS) decays in which there is both interference between two different decay amplitudes and a strong phase shift from final state interactions. The expected SM CP violation in non-leptonic decay of the neutral charmed meson is generated from interference of decays with and without mixing in the absence of direct CP violation in Cabibbo favored (CF) and doubly Cabibbo suppressed (DCS) decays. The SM also predicts a CP asymmetry in the final states containing a neutral kaon that is produced via $K^0 - \bar{K}^0$ mixing even if no CP violating phase exists in the charm decays itself and we refer to it as $A_{CP}^{K_S^0}$. The magnitude of $A_{CP}^{K_S^0}$ is $(0.332 \pm 0.006)\%$ [3] if DCS decay contributions are ignored.

In this presentation, we report CP asymmetries of charmed mesons in the decays $D \rightarrow K_S^0 P$, where D denotes D^0 and $D_{(s)}^+$, and P denotes the pseudo-scalar mesons π^+ , K^+ , π^0 , η , and η' [4]. We also report the CP asymmetry difference between SCS decay $D^+ \rightarrow \phi \pi^+$ and CF decay $D_s^+ \rightarrow \phi \pi^+$ in the region of $|M(K^+ K^-) - M_{PDG}^\phi| < 16 \text{ MeV}/c^2$. Among the decays listed above, $D^+ \rightarrow K_S^0 K^+$ and $D_s^+ \rightarrow K_S^0 \pi^+$ are SCS decays and others are mixtures of CF and DCS decays, where SM CP violations described above are expected. Interference between CF and DCS could generate $\mathcal{O}(1)\%$ of direct CP asymmetry if unknown new physics processes are responsible for additional weak phases [5]. Physics beyond the SM could also induce direct CP asymmetry ($\mathcal{O}(1)\%$) in D meson decays [6]. Since CP asymmetries expected by the SM in the decays considered in this presentation is much smaller than $A_{CP}^{K_S^0}$, observing A_{CP} inconsistent with $A_{CP}^{K_S^0}$ would represent strong evidence for processes involving physics beyond the SM [5][6]. The data were recorded at or near the $\Upsilon(4S)$ resonance with the Belle detector [7] at the e^+e^- asymmetric-energy collider KEKB [8]. The sample corresponds to an integrated luminosity of $673/791/854 \text{ fb}^{-1}$ depending on the decay mode.

We determine the quantity $A_{CP}^{D \rightarrow f}$ defined in Eq. (1) by measuring the asymmetry in the signal yield

$$A_{\text{rec}}^{D \rightarrow f} = \frac{N_{\text{rec}}^{D \rightarrow f} - N_{\text{rec}}^{\bar{D} \rightarrow \bar{f}}}{N_{\text{rec}}^{D \rightarrow f} + N_{\text{rec}}^{\bar{D} \rightarrow \bar{f}}} = A_{CP}^{D \rightarrow f} + A_{\text{other}}, \quad (2)$$

where N_{rec} is the number of reconstructed decays. A_{other} is asymmetry other than A_{CP} and it contains the forward-backward asymmetry (A_{FB}) due to $\gamma^* - Z^0$ interference in $e^+e^- \rightarrow c\bar{c}$ and the other is a detection efficiency asymmetry between positively and negatively charged hadrons and the latter depends on decay mode. With assumption the A_{FB} is the same for all charmed mesons, we correct for A_{other} using a large statistics of real data samples. The detailed correction procedures are described in Refs. [9][10][11]. Once we correct for A_{other} , then $A_{CP}^{D \rightarrow f}$ is obtained in bins of corresponding phase spaces (shown in Fig. 1) and the measured A_{CP} values are listed in Table 1.

The CP asymmetry difference between SCS decay $D^+ \rightarrow \phi \pi^+$ and CF decay $D_s^+ \rightarrow \phi \pi^+$ (ΔA_{CP}) is obtained by subtracting $A_{\text{rec}}^{D_s^+ \rightarrow \phi \pi^+}$ from $A_{\text{rec}}^{D^+ \rightarrow \phi \pi^+}$ since the kinematics of $D^+ \rightarrow \phi \pi^+$

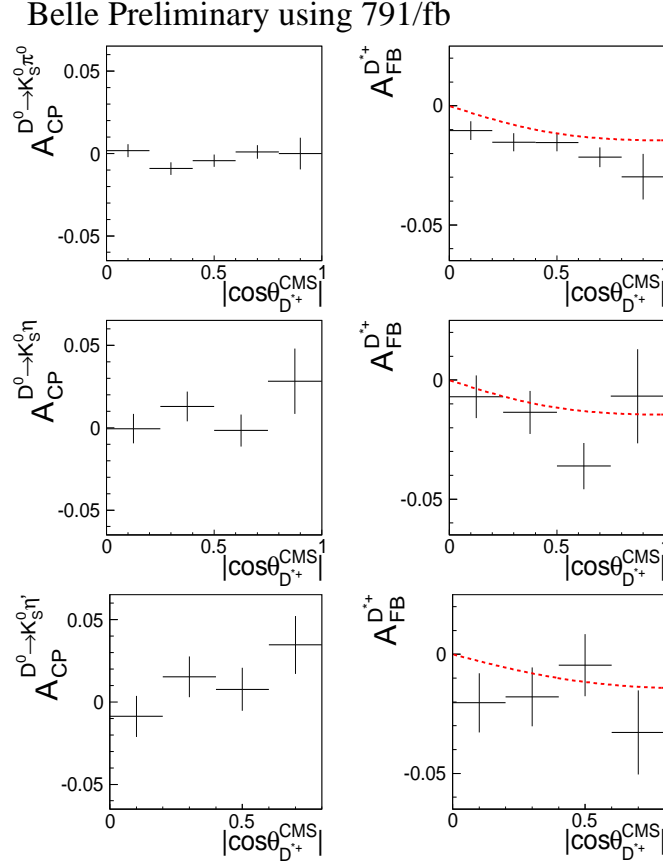


Figure 1: Preliminary results of A_{CP} (left) and A_{FB} (right) values as a function of $|\cos \theta_{D^{*+}}^{\text{CMS}}|$. Top plots are for $K_S^0 \pi^0$, middle plots for $K_S^0 \eta$, and bottom plots for $K_S^0 \eta'$ final states. The dashed curves show the leading-order prediction for $A_{FB}^{c\bar{c}}$.

Table 1: Summary of the A_{CP} measurements. The first uncertainties are statistical and the second are systematic. The \ddagger is the total uncertainty. The \dagger 's are preliminary results.

Decay Mode	A_{CP} (%) (Belle)	A_{CP} (%) (current world best or world average)	$A_{CP}^{K_S^0}$ (%)
$D^+ \rightarrow K_S^0 \pi^+$	$-0.71 \pm 0.19 \pm 0.20$	$-1.3 \pm 0.7 \pm 0.3$	-0.332
$D^+ \rightarrow K_S^0 K^+$	$-0.16 \pm 0.58 \pm 0.25$	$-0.2 \pm 1.5 \pm 0.9$	-0.332
$D_s^+ \rightarrow K_S^0 \pi^+$	$+5.45 \pm 2.50 \pm 0.33$	$+16.3 \pm 7.3 \pm 0.3$	+0.332
$D_s^+ \rightarrow K_S^0 K^+$	$+0.12 \pm 0.36 \pm 0.22$	$+4.7 \pm 1.8 \pm 0.9$	-0.332
$D^0 \rightarrow K_S^0 \pi^0$	$-0.28 \pm 0.19 \pm 0.10^\dagger$	$+0.1 \pm 1.3^\ddagger$	-0.332
$D^0 \rightarrow K_S^0 \eta$	$+0.54 \pm 0.51 \pm 0.16^\dagger$	N.A.	-0.332
$D^0 \rightarrow K_S^0 \eta'$	$+0.90 \pm 0.67 \pm 0.14^\dagger$	N.A.	-0.332

and $D_s^+ \rightarrow \phi\pi^+$ are quite similar with each other. Besides the ΔA_{CP} , the production difference between D^+ and D_s^+ (ΔA_{FB}) is also obtained by the subtraction. Figure 2 shows the measured ΔA_{CP} and ΔA_{FB} in bins of corresponding phase space in the region of $|M(K^+K^-) - M_{PDG}^\phi| < 16$ MeV/ c^2 . By fitting the ΔA_{CP} points with a constant, we obtain a preliminary result of $\Delta A_{CP} = (0.62 \pm 0.30 \pm 0.15)\%$ where the first uncertainty is statistical and the second is systematic. The ΔA_{FB} plot in Fig. 2 shows no significant difference between forward-backward asymmetries in the production of the D^+ and D_s^+ mesons.

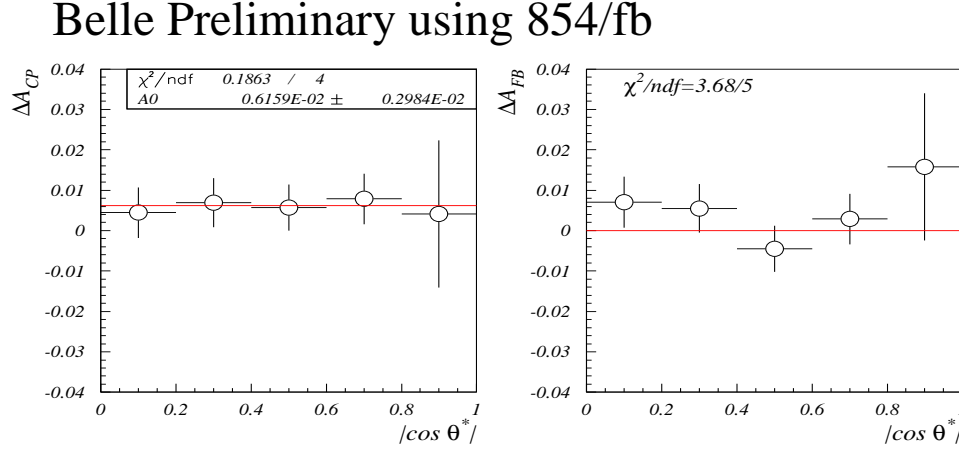


Figure 2: Preliminary results of ΔA_{CP} (left) and ΔA_{FB} (right) values as a function of $|\cos \theta^*|$. The line in left plot shows the fit with a constant and that of right shows the hypothesis test for a null ΔA_{FB} hypothesis.

In summary, we have searched for CP violation in several charm decays. No evidence for CP violation is observed at sensitivities greater than 0.2% depending on the decay mode. We also find no significant difference between forward-backward asymmetries in the production of the D^+ and D_s^+ mesons.

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